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Pictures help people to comprehend and remember texts. The goal of this project is to begin to understand how this occurs. Section I of this report contains a summary of work on several subgoals. Section II contains the report of two experiments testing the assumption that pictures provide an external memory which can assist working memory and thereby facilitate comprehension. We predicted that the availability of a diagram would interact with the difficulty of resolving anaphor references in texts. Resolution of an anaphor distant from its antecedent (which should stress working memory) should benefit greatly from a picture, whereas resolution of an anaphor near to its antecedent should benefit less from a picture. In experiments involving both cumulative and moving window presentations of texts, picture availability and distance separating antecedent from anaphor were manipulated. Although both picture presence and ease of anaphor resolution significantly improved subjects' comprehension of the material, no evidence was found for an interaction of these factors. The results are interpreted as consistent with either dual code theory or aspects of working memory management that do not involve anaphor resolution.

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The project "Comprehension of Illustrated Text" is directed toward producing an understanding of the facilitative effects of pictures on comprehension of texts. Both comprehension processes and the results of those processes (cognitive representations) are considered. This technical report is divided into two sections. The first presents a summary of work completed during the previous year and work in progress, including a list of publications and presentations. The second section is a complete report of experimental work designed to investigate one comprehension processes affected by pictures.

Section I: Summary of work completed and in progress

A. Work Completed

1. Pictures facilitate construction of mental models. Our experimental work has demonstrated that one way in which pictures help comprehension is by providing a framework for the construction of a mental model, a representation of what the text is about (e.g., the components of a machine or the steps in a procedure) as opposed to a representation of the text itself (words and sentences). This work is reported more fully in the 1990 Annual Technical Report, and a version of it (Glenberg and Langston) is in press.

2. Pictures and anaphora. An important component of text comprehension is the resolution of anaphoric relations. That is, anaphors, such as pronouns, require reference to previously presented information, antecedents, to uncover their contextually explicit meaning. Anaphor resolution is a major component in providing textual coherence. We hypothesized that pictures would facilitate anaphor resolution by providing an external memory for potential antecedents. Thus a glance at the picture would provide access to antecedents that would otherwise have to be uncovered through a more laborious search of the text or memory. This hypothesis received little empirical support. A report of the major experiments will be submitted for publication by August 15, 1991, and the experiments are described in detail in Section II of this technical report.

B. Work in progress

1. Work on the "noticing hypothesis." We have evidence (Glenberg and Langston) that pictures help readers to form mental models. But why should this help comprehension? One hypothesis is that the mental models allow readers to "notice" significant relations in the model of the situation that are not explicit in the text. We have conducted several experiments testing this hypothesis, but we are not satisfied with any of them. Internal analyses of the results reveal that subjects in the experiments have found ways of doing that task that preclude noticing.

2. External memory hypothesis. We have conducted experiments testing the hypothesis that pictures act as a form of external memory which can be used to supplement a reader's working memory. So far, we have been able to demonstrate that pictures do not enhance general working memory capacity, but they do affect the component of working memory identified as the visual-spatial sketchpad.

3. Pictures and memory for what people say. Professor Thomas Grimes (now at Kansas State University) and I have been collaborating on a project to determine if seeing a picture of a speaker helps one to remember wh the speaker has said. We have conducted experiments that demonstrate a) pictures do facilitate memory in this way, and b) the effect depends on using actual pictures of speakers; it is not found when geometric symbols replace the faces. A current experiment is investigating two explanatory hypotheses. The first is that having the picture allows the subject to create a more concrete (and memorable) representation of the information. The second is that subjects use the picture to generate a stable personality profile of the speaker and that the speaker's statements are integrated into that profile.

4. Computer simulation. My graduate students and I have developed a computer simulation of the major processes that we believe occur when reading a text accompanied by a picture. The simulation derives propositions from simplified texts and uses those propositions to build mental models of the situation described by the text. Based on relations within the mental model, new propositions are inferred. Pictures are used in several ways. First, pictures disambiguate relations described by the text. For example, if the text states that "A is near B," it is not clear if A is to the left of B, the right of B, under B, etc. Second, pictures provide metric information about locations. Third, pictures reduce the amount of cognitive processing required to maintain symbols in the mental model when those symbols correspond to objects in the picture. Our initial efforts with the computer model has produced a gratifying degree of success in simulations of text comprehension experiments, memory experiments, and map learning experiments.

C. Publications and presentations.

Glenberg, A. M. Building mental models from text: A simulation of comprehension and memory. Invited address, ARMADILLO-II conference, Texas A&M University, May, 1991.

Glenberg, A. M. Comprension del texto illustrado: los dibujos ayudan a crear modelos mentales. Invited address, University of Salamanca, July, 1991.

Glenberg, A. M. Building mental models from text: A simulation of comprehension and memory. Invited address, Human Communication Research Centre, University of Edinburgh, July 1991.

Glenberg, A. M., and Langston, W. E. (in press). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language.*

Glenberg, A. M., and Langston, W. E. (1991, May). Comprehension of illustrated text: Pictures help to build mental models. In A. M. Glenberg and M. McDaniel (Co-chairs), *Mental models, pictures, and text: integration of spatial and verbal information.* Symposium conducted at the meeting of the Midwestern Psychological Association.

Glenberg, A. M., and Kruley, P. (manuscript submitted for publication). Pictures and anaphora: Evidence for independent processes. *Memory & Cognition.*

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Section II: Pictures and anaphora: Evidence for independent processes

Abstract

Pictures enhance comprehension of written texts, but the perceptual and cognitive processes that underlie this effect have not been identified. Because integrating the information contained in a text places demands on working memory, the effect of a picture may be to expand the functional capacity of working memory, and thereby facilitate comprehension. Based on this reasoning, we predicted that the availability of a diagram would interact with the difficulty of resolving anaphor references in texts. Resolution of an anaphor distant from its antecedent (which should stress working memory) should benefit greatly from a picture, whereas resolution of an anaphor near to its antecedent should benefit less from a picture. In experiments involving both cumulative and moving window presentations of texts, picture availability and distance separating antecedent from anaphor were manipulated concurrently. Although both picture presence and ease of anaphor resolution significantly improved subjects' comprehension of the material, no evidence was found for an interaction of these factors. The results are interpreted as consistent with either dual code theory or aspects of working memory management that do not involve anaphor resolution.

It is a fact that pictures help people to learn from texts (see Willows and Houghton, 1987, for reviews of the literature). What is less certain, is exactly how pictures have this salutary effect. The experiments reported here were designed to investigate a possible beneficial effect of pictures on an important process of text comprehension, anaphor resolution. To foreshadow our results, we found, once again, that pictures enhance comprehension. Nonetheless, we were not able to adduce any evidence that the enhancement was due to a direct effect of pictures on anaphor resolution. We discuss several ways in which pictures can aid comprehension without affecting anaphor resolution.

Our tact is to investigate the general hypothesis that pictures enhance working memory management. Most theories of text comprehension (e.g., Kintsch, 1988) specify that an important aspect of comprehension is the building of a representation (see also Gernsbacher, Varner, and Faust, 1990), and that the representation is built using the facilities of working memory. Because working memory is thought to be severely limited in the amount of information that can be represented at one time, the comprehender may find it necessary to shunt information into and out of working memory (that is, to manage it) while building the appropriate structures. Fletcher and Bloom (1988), for example, have investigated various strategies for controlling the contents of working memory during reading. Pictures may facilitate working memory management in several ways. For example, pictures can serve as an external memory, so that the reader can avoid searches of long-term memory or the text itself, when information is required. Larkin and Simon (1987) demonstrated how pictures may enhance a search of this sort. Glenberg and Langston (in press) demonstrated that pictures can lead to a reorganization of information in working memory. In that experiment, subjects read texts describing four-step procedures. The texts described both the content of the steps and the order in which the steps were to be performed. When reading without a picture, subjects tended to represent the steps in the order in which they were presented in the text. When reading the same texts accompanied by pictures illustrating the order of the steps when the procedure is executed, subjects tended to represent the order of the steps as executed, rather than as described in the text.

Anaphora resolution is a comprehension process that is sensitive to working memory management. An anaphor is a word or phrase that is interpreted in relation to previous elements of the discourse (the antecedent or referent of the anaphor). Pronouns are prototypical anaphors, in that the interpretation of a pronoun (e.g., the word "it") often requires reference to a previous description in the text. Nonetheless, anaphors may be noun phrases, synonyms of previous nouns, temporal referents such as "the former" (Jakimik and Glenberg, 1990), or even the absence of a noun (see Halliday and Hasan, 1976). Successful anaphor resolution is probably an important component in generating a sense of coherence, that the sentences in a text belong together.

The process of anaphor resolution is sensitive to distance between the anaphor and its antecedent. It takes longer to accomplish anaphor resolution when the anaphor and its antecedent are far from one another in the text than when they are close together (e.g., in adjacent sentences). Demonstrations of this distance effect may be found in Clark and Sengul (1979), Daneman and Carpenter (1980), and Ehrlich and Rayner (1983).

A standard interpretation of this distance effect is that it reflects a type of working memory management. Antecedents that are near to their anaphors are likely to be represented in working memory (or foregrounded) when the anaphor is read. When the antecedent is far from the anaphor, the antecedent may not be in working memory, and it must be reinstated to resolve the anaphor. This reinstatement process takes time and produces the distance effect.

We anticipated that pictures would facilitate this reinstatement process and thereby provide for smooth and effective comprehension. Our reasoning was based on the idea that a picture may serve as an external memory which is easier to search than either the physical text or the representation of the text in long-term memory (Larkin and Simon, 1987). This reasoning predicts an interaction between distance and whether or not a picture accompanies the text. When the antecedent and the anaphor are close in the text, the antecedent should be represented in working memory, so that the picture makes little difference. However, when the antecedent and the anaphor are far apart, the antecedent needs to be reinstated in working memory, and the picture should facilitate reinstatement.

Although we anticipated this interaction, our experiments were designed to discriminate among several hypotheses. First, it may be that pictures need to be perceptually present to facilitate reinstatement of antecedents (perceptual hypothesis). Second, it may be that exposures to pictures creates a memory representation (of the picture) that can be used to facilitate reinstatement in the absence of the physical picture (memory hypothesis). Third, contrary to our expectations, pictures may not affect anaphor resolution, but may enhance comprehension through other means (general facilitation hypothesis).

Subjects read texts containing a short scientific description of a single object, typically a living organism, a part of an organism, or a mechanical device (some examples: the sphagnum sporophyte, the structure of a leaf, and a solar collector). Either four or five distinct parts of the object were described in the text; antecedent sentences described names and locations of the parts, and anaphor sentences repeated the spatial location (but not the name) and presented one fact about the part. Each text used in the study conformed to the structure shown in Table 1. This structure includes two anaphoric references, one to a referent mentioned in the immediately

Table 1

Sample Text Used in the Study

Segment Name	Text
Introduction:	The sphagnum sporophyte is the reproductive system of a fungus that grows on plants.
Antecedent 1:	The operculum is at the top of the sphagnum sporophyte.
Fillers:	The fungus's spores are contained in an arc-shaped central column surrounded by a sterile region called the columella.
Antecedent 2:	The pseudopodium is on the bottom of the fungus.
Near Anaphor:	The part on the bottom elevates the entire sporophyte.
Coherence Sentence 1:	Elevation increases the distribution of spores when they are released.
Far Anaphor:	The part at the top maintains internal pressure
Coherence Sentence 2:	This internal pressure is what will eventually cause the sphagnum sporophyte to pop and release the spores.

Near Question:	What does the pseudopodium do? a. releases spores b. elevates the sporophyte c. nourishes the sporophyte d. creates pressure. (Answer: b.)
Far Question:	What is the function of the operculum? a. to elevate the sporophyte b. to distribute spores c. to maintain internal pressure d. to aid in attachment. (Answer: c.)
Filler Question:	Which part surrounds the central chamber? a. foot b. columella c. pseudopodium d. operculum (Answer: b.)

preceding sentence ("Near Anaphor", which refers to "Antecedent 2"), and the other to a referent mentioned three or more sentences previously ("Far Anaphor", referring to "Antecedent 1"). In both cases, the anaphor was a definite noun phrase describing a spatial location, such as, "the part on the bottom." Antecedent and anaphor segments were all short declarative sentences in which antecedent and anaphor phrases occurred at the beginning of the sentence. The role of the Filler and Coherence Sentence segments was twofold: first, to increase the distance in the text between the far anaphor and its antecedent, and second, to improve the coherence of the texts. To control for effects of specific sentences on reading time and comprehension, the texts were designed so that either critical sentence could serve as Near or Far Anaphor.

In addition, texts were sometimes accompanied by pictures. Figure 1 is the picture that could accompany the text in Table 1. Pictures showed the structural relationships between parts of the object in a level of detail typical of a high-school or undergraduate textbook. For many of the objects, the picture suggested a three-dimensional representation. Each part of the object named in the text was labeled in the picture.

On one-third of the trials, a picture accompanied the text (full picture condition). On one-third of the trials, a picture accompanied the text, but it disappeared before the near anaphor sentence was displayed (disappearing picture condition). For the remaining texts, no picture was shown (no picture condition). Consider the predictions from the three hypotheses outlined previously. First, suppose that the picture must be perceptually available to facilitate anaphor resolution. In this case, distance and picture condition should interact. That is, a distance effect should be found in the no picture condition, but this distance effect should be substantially reduced in the full picture condition. The disappearing picture condition should parallel the no picture condition, because the hypothesis supposes that the picture must be perceptually present to facilitate reinstatement of distant antecedents. Second, suppose that pictures result in a mental representation that can be used to facilitate reinstatement of antecedents (memory hypothesis). In this case, there should again be an interaction between distance and picture condition, but the disappearing picture condition should parallel the full picture condition (the distance effect should be reduced in both cases). Finally, consider the possibility that pictures enhance comprehension, but not anaphor resolution (general facilitation hypothesis). In this case, pictures will produce a main effect (better performance than in the no picture condition), but there should not be an interaction with distance.

We used two dependent variables. One was reading time. Subjects pressed a key to expose successive parts of the text, and the time between key presses was recorded. In this case, an interaction between distance and picture condition would be revealed by a) an increase in reading time with distance in the no picture condition, and

The Sphagnum Sporophyte

— Operculum

— Spores

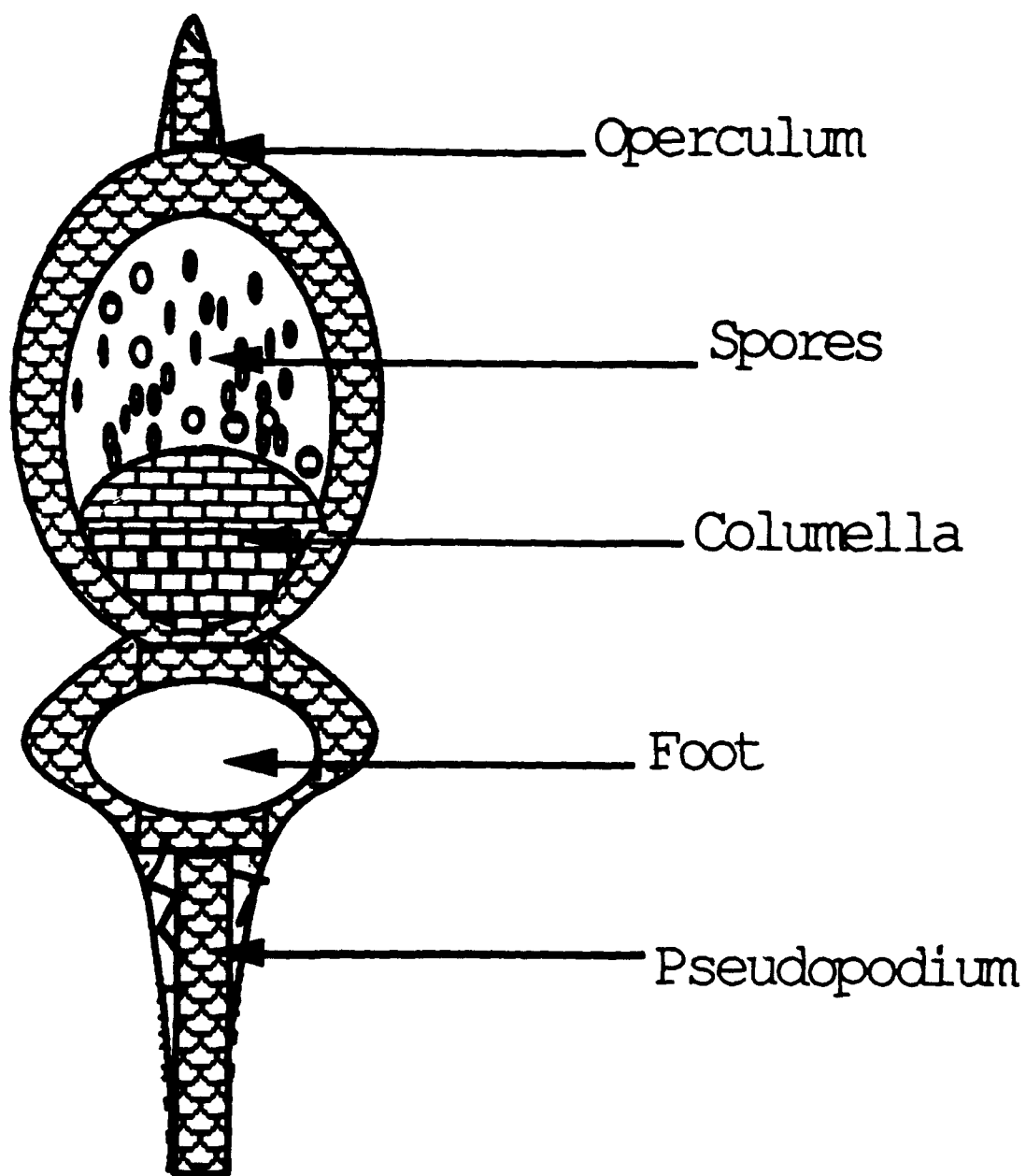— Columella

— Foot

— Pseudopodium

Figure 1. The diagram presented with the text of Table 1

b) a smaller increase (or no increase) with distance in the picture conditions. Unfortunately, this prediction may be compromised by the mechanics of the reading situation. That is, subjects must physically move their eyes from the text to the picture, and this will take some time. Thus if subjects only refer to the picture in the far condition, the eye movement time will be added only in this condition, working against the predicted interaction. Also, having the picture present may induce other strategies, such as using the text to build a cognitive model of the object, and using the picture as a check for accuracy. Thus the picture may slow down reading, rather than speeding it. For these reasons, we included performance on comprehension questions as a second dependent variable.

The "near" comprehension question required integration of information presented in the sentences containing the near antecedent and the near anaphor. That is, the Antecedent 2 sentence provided the name of a part (e.g., "the pseudopodium") and its location (e.g., "on the bottom"). The Near Anaphor sentence referred to the part using the spatial location (e.g., "the part on the bottom") and described the function of the part (e.g., "elevates the entire sporophyte"). The comprehension question required the association of the name (from the antecedent sentence) and the function (from the anaphor sentence). Similarly, the "far" comprehension question required integration of information presented in the Antecedent 1 sentence and the Far Anaphor sentence. When performance on the comprehension questions is the dependent variable, and interaction between distance and picture condition would be revealed by a) a decrease in percent correct with distance in the no picture condition, and b) a smaller decrease (or no decrease) in the picture conditions.

Before subjects read the texts, we measured their reading spans. Daneman and Carpenter (1980) demonstrated that reading span correlated with success in resolving distant referents of pronouns. Supposedly, readers with large reading spans can more easily maintain in working memory potential referents than can readers with smaller spans. On the assumption that pictures facilitate working memory management, we expected the following pattern of correlations. Memory span should correlate with performance in the far condition when there are no pictures and readers are forced to rely on their own memories. The correlation should be substantially reduced, however, when pictures are present and readers can use the pictures to supplement their own memories. Unfortunately, the correlations with reading span were all low and unsystematic across the experiments. Thus we will not discuss the reading span measure further except to indicate its presence in the procedure.

Method

Subjects. The 48 subjects included both paid participants and students enrolled in introductory

psychology courses at the University of Wisconsin-Madison. The latter received extra credit for participating. All of the subjects were paid a cash bonus based on the total number of correct responses on the comprehension questions. Six additional subjects were replaced, five because computer failures made it impossible to analyze their data, and one for failing to exceed chance performance on the comprehensions questions.

Materials and design. A total of 35 texts (3 practice, 32 experimental) were used, each with a corresponding labeled diagram (as shown in Figure 1). Comprehension questions, which tested for knowledge of both spatial and factual information, were designed to motivate subjects to read all sentences carefully; as a further incentive subjects were informed in advance of the payment of 10 cents for each correct answer. Three comprehension questions in multiple choice format, each with four possible answers, were prepared for each text (see Table 1). Correctly answering the "Near Question" required subjects to integrate information found in the Antecedent 2 and Near Anaphor sentences. Similarly, a "Far Question" required integrating Antecedent 1 and the Far Anaphor. "Filler Questions" were included to prevent subjects from identifying specific segments of the text upon which to focus attention.

Texts and pictures were displayed side-by-side on a Macintosh color monitor. Upon responding to a prompt, the subject was shown the diagram and the title of the text. Each subsequent key press revealed the next sector (see below) of the text. In the No Picture condition, the portion of the screen allocated for the picture remained blank, and only the text was shown; in the Disappearing Picture condition, the diagram disappeared after the key press that revealed the Near Anaphor sentence (as identified in Table 1); in the Full Picture condition both picture and text remained visible until the key press following the final word in the text. Thus the difference between Disappearing and Full Picture conditions was the status of the picture while reading the critical anaphor sentences.

Eight of the 32 experimental texts were used as unscored distractor texts. These texts, which were intended as a further guard against subject strategizing, included some comprehension questions that did not follow the Near/Far/Filler scheme. In addition, for these texts, the picture disappeared after the presentation of a randomly selected word, rather than after the end of Antecedent 2. The same eight texts were used as distractors for all subjects.

Two factors were manipulated within subjects. One factor was picture presence: each subject read 8 texts in each of the three conditions (No Picture, Disappearing Picture, and Full Picture). The second factor was anaphor distance, with two levels: near and far. Each text contained a near and far anaphor, each with a related

comprehension question. Texts were presented in a different random order for each subject, with each text appearing equally often in the three picture conditions. In addition, each text was seen equally often in its standard order and with Near and Far Anaphor sentences (and corresponding antecedent and coherence sentences) interchanged.

Procedure. Subjects were instructed to aim for comprehension. They were also instructed that pictures might disappear, "as if they had turned the page of a book." After the display of the title and diagram, texts were presented one word at a time in a cumulative display: the text was initially shown with dashes representing the letters in each word. Readers controlled the rate of presentation by pressing the space bar when they were ready for a new word; after the key press, one sector of the text became visible, replacing the dashes that had represented it. A sector of text was normally a single word, but two-word infinitive phrases and those beginning with an article (e.g., "the operculum") were presented as single sectors. Previously exposed sectors remained visible on the screen. The reading time (time between key presses in msec) on each segment of the text was measured. In the practice trials only, after reading a text, subjects answered the three multiple choice comprehension questions in sequence by typing in the letter of the alphabet corresponding to the chosen answer. During the experimental portion, subjects read a block of four texts, then they answered the twelve questions relating to the texts in the block.

Results

After analyzing the data, it was found that one subject's total of 21 correct answers was more than 3 standard deviations below the overall mean; this subject was omitted from all analyses.

Reading Times. Median reading times in each of the picture conditions for each subject were computed for the critical anaphor sentences; the means of these median reading times are shown in Figure 2[1]. The expected effect of distance was found for the Full Picture and Disappearing picture conditions. That is, subjects took longer to read the sentence containing the far anaphor than the sentences containing the near anaphors. There is also evidence of an interaction between between picture condition and distance. Note however, that this interaction is the opposite of the one predicted by the perceptual hypothesis and by the memory hypothesis. That

For two reasons, the main analysis is on the time to read the anaphor sentences, rather than the time to read the anaphor sectors of the sentences. First, because of a programming error, the sector data were not available for all of the texts. Second, because the previously exposed text was available for inspection, some subjects might have elected to expose the whole anaphor sentence (by multiple key presses) before reading the sentence carefully. In any event, an analysis of the times spent on the anaphor sectors was in all essential respects like the analysis of the whole sentences. In addition, the methodology used in Experiment 2 will allow an analysis of the time to read the anaphor sectors as well as the time to read the anaphor sentences.
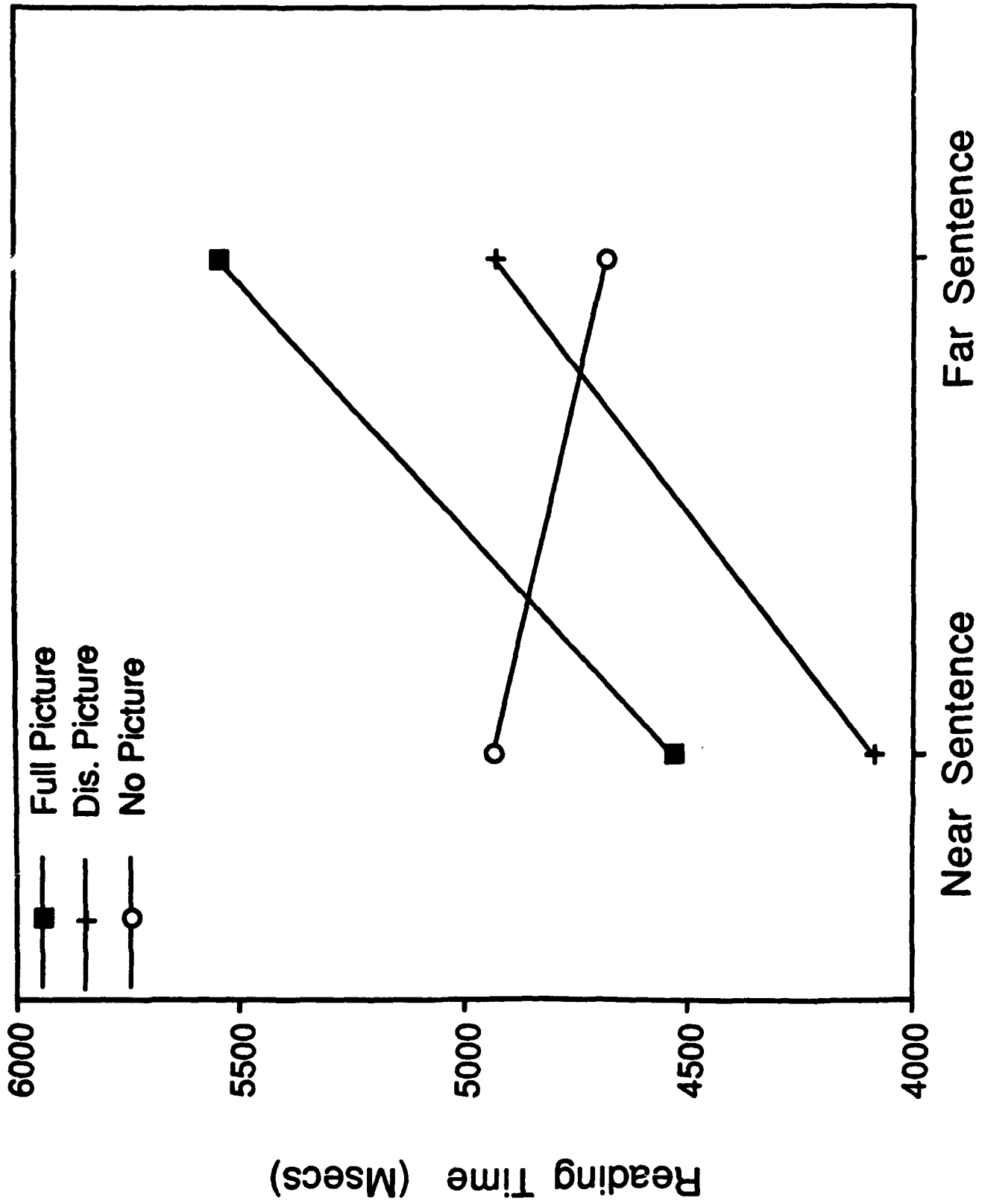
Figure 2. Mean of subjects' median reading times in Experiment 1 as a function of anaphor distance and picture presence.

is, instead of speeding reading by facilitating anaphor resolution in the far condition, the pictures appear to have slowed reading relative to the No Picture condition. These observations were confirmed by analyses of variance (ANOVA) performed using subjects as the random effect (statistics reported as "$F1$") and using texts as the random effect ("$F2$"). In all cases, an alpha level of .05 has been used for significance tests. The main effects of picture, distance and the picture by distance interaction were all significant. For picture, $F1(2,92)$ was 3.27, MSE = 2036189, $F2(2,46)$ = 6.67, MSE = 975448; for distance, $F1(1,46)$ = 10.78, MSE = 1875759, $F2(1,23)$ = 31.29, MSE = 532208; for the interaction, $F1(2,92)$ was 5.98, MSE = 1856294, $F2(2,46)$ = 7.62, MSE = 820365. Simple effects analyses indicated that the pattern of increasing reading time with increasing distance was significant in both disappearing picture ($F1(1,46)$ = 7.26, MSE = 2280009, $F2(1,23)$ = 15.00, MSE = 626394) and full picture conditions ($F1(1,46)$ = 14.52, MSE = 1679978, $F2(1,23)$ = 20.42, MSE = 958342); in the no picture condition, in contrast, the simple effect of distance was not significant ($F1(1,46)$ = .91, MSE = 1628361, $F2(1,23)$ = .30, MSE = 588201).

Accuracy. In a task in which 25% constitutes chance performance, mean overall accuracy responding to comprehension questions was 81.1% (see Figure 3). Main effects were significant for both picture ($F1(2,92)$ = 5.10, MSE = 224.23, $F2(2,46)$ = 3.32, MSE = 166.62) and distance ($F1(1,46)$ = 13.43, MSE = 224.23, $F2(1,23)$ = 5.90, MSE = 180.72). Predictably, accuracy increased as distance in text decreased, and as picture availability increased. A central theoretical prediction involved a picture-by-distance interaction, but the interaction did not even approach significance ($F1(2,92)$ = 0.45, MSE = 139.05, $F2(2,46)$ = 0.43, MSE = 65.33).

Analysis By Reading Speed. Because individuals vary widely in reading speed and reading strategies, a median split was made on the basis of overall reading time, and the data were analyzed using this factor. The one subject with the median overall reading time was omitted from the analysis. No difference was found between slow and fast readers on the comprehension measure ($F1(1,44)$ = .54, n.s.). For the sentence reading times, the three-way interaction of reading speed, distance, and picture was significant ($F1(2,88)$ = 4.50); simple effects analyses indicated the presence of a distance by picture interaction for slow readers ($F1(2,88)$ = 10.21), whereas this interaction was not significant for fast readers ($F1(2,88)$ = .05). Figure 4 shows the pattern of reading times for the slow readers; in this group, reading time did not increase with distance in the No Picture condition. Importantly, data from both the slow readers and the fast readers were contrary to the predictions derived from the memory hypothesis and the perceptual hypothesis.

Analysis By Half of Experiment. To test for an interaction between theoretical factors and either practice or fatigue effects, performance during the first and second halves of the experiment was compared. For the percent
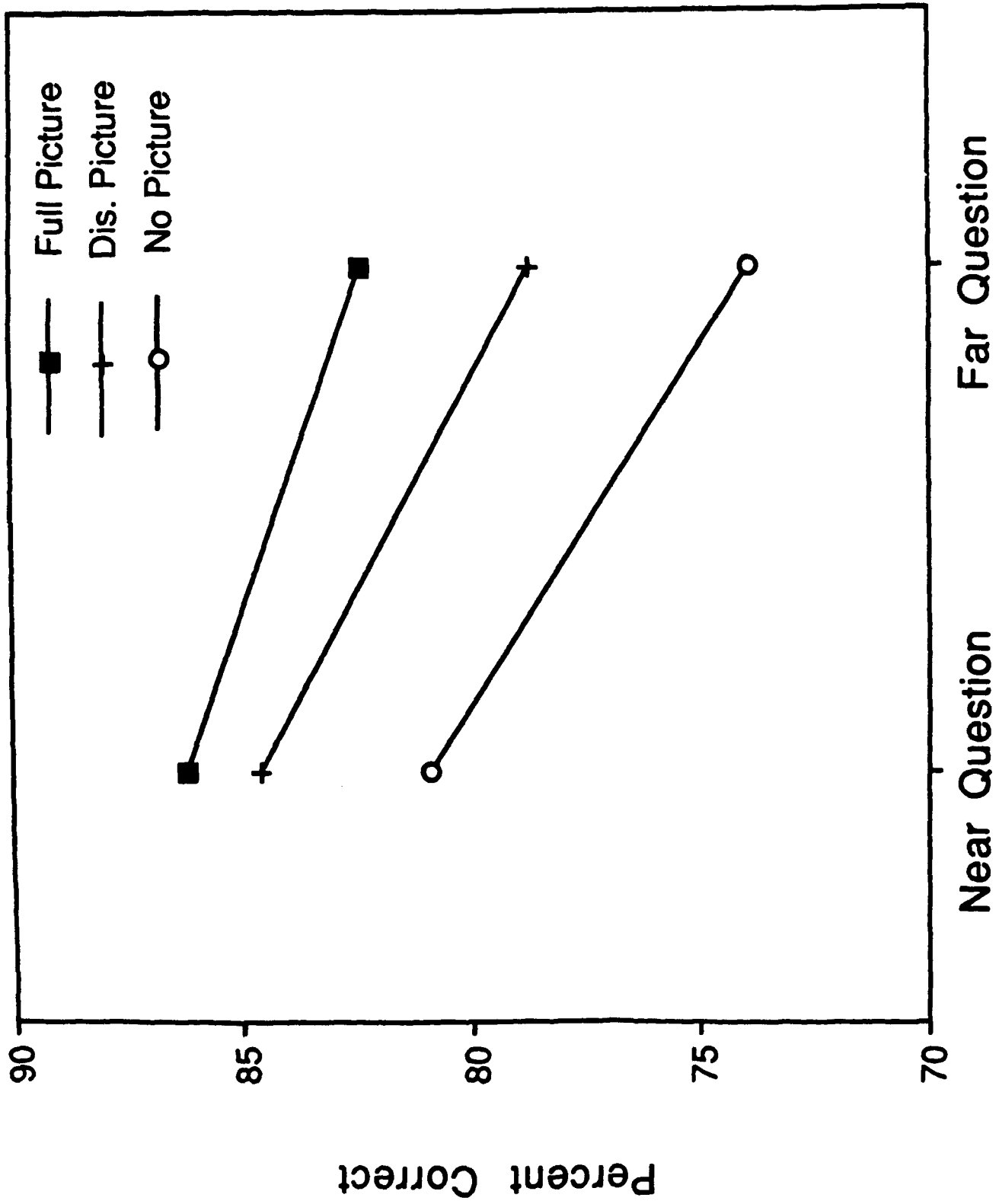
Figure 3. Mean percent correct in Experiment 1 as a function of distance and picture conditions.
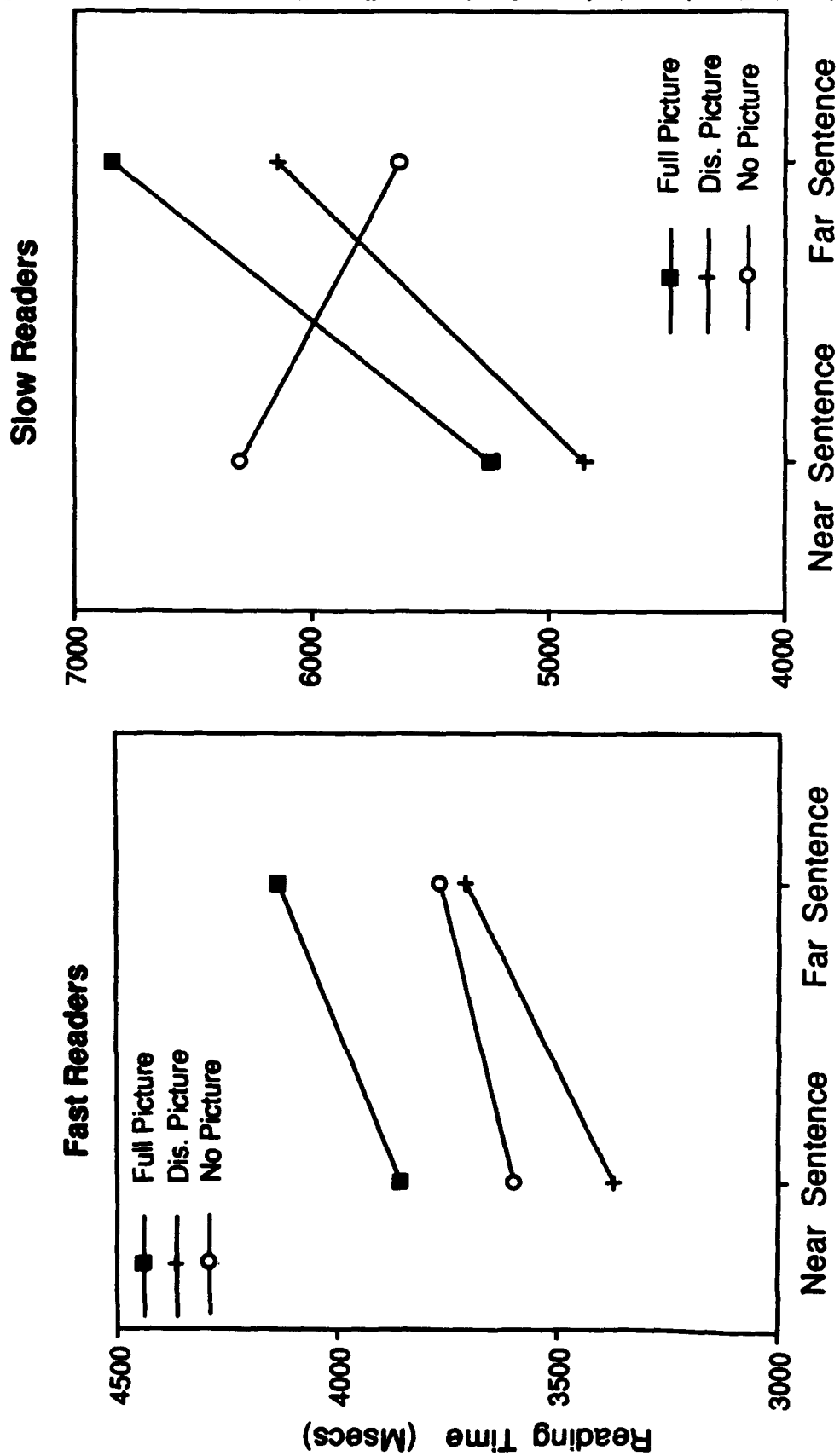
Figure 4. Reading times in Experiment 1 after performing a median split on overall reading speed. Panel (a) shows the pattern of reading times for slow readers, and panel (b) for fast readers.

Slow Readers

7000
6000
5000
4000

Near Sentence   Far Sentence

Full Picture
Dis. Picture
No Picture

Fast Readers

4500
4000
3500
3000

Near Sentence   Far Sentence

Reading Time (Msecs)

Full Picture
Dis. Picture
No Picture

correct measure, the second half mean was higher than the first half (81.1 vs. 79.7), but neither the main effect nor any interaction was significant ($F1$ < 1.40, p > .25 in all cases). There was a significant main effect of half on sentence reading times ($F1$(1,46) = 15.81, MSE = 142271860), with subjects taking 1005 msec longer to read critical sentences during the first half. Interactions involving half were non-significant, ($F1$ < 2.19, p > .10 in all cases).

Discussion

We used distance as a conceptual marker for anaphor resolution, thus interpretation of the results requires that we demonstrate a significant distance effect. Indeed, the distance effect was significant for both dependent variables; resolution of far anaphors required more time and produced less accurate question answering than resolution of near anaphors. We are not certain why there was no distance effect in the reading times in the no picture condition. Perhaps subjects find the task so difficult (in the absence of pictures) that they read all of the sentences very slowly. Given that the distance manipulation was effective, what can we say about the three hypotheses described in the introduction? There was an interaction between distance and picture condition, but this interaction was just the opposite of that predicted by the perceptual hypothesis and the memory hypothesis. That is, when subjects had pictures available, they read the far anaphor sentence slower than the near anaphor sentence. The interaction we obtained provides no support for the two hypothesis, but neither is the interaction fatal. As mentioned in the introduction, the picture may induce reading strategies that would countermand the predictions regarding reading times. Because of this possibility, we included the comprehension questions. Unfortunately for the perceptual and memory hypotheses, the comprehension question data do appear to be fatal. There was a distance effect, but little or no evidence for an interaction of distance and picture condition. Thus the weight of the evidence is that pictures do not affect anaphora resolution.

Experiment 2

There are several reasons for being suspicious about the conclusion that pictures do not affect anaphor resolution. First, it depends on accepting the null hypothesis (we will present a power analysis in the General Discussion). Second, it rests in part on the comprehension question data, which is an off-line measure, whereas anaphor resolution is an on-line process. Third, it may be peculiar to the experimental context. That is, subjects may have become sensitive to the requirements of the comprehension questions and chosen to read exceptionally

carefully, and perhaps reread the text, whether or not the picture was available. This strategy may have been encouraged by the continuous availability of the text. Experiment 2 was conceptually similar to Experiment 1, except for two changes. First, a moving window methodology (Just, Carpenter, and Wooley, 1982) was used. Each key press exposed a single word (or short phrase) and erased the previously exposed text. This methodology eliminates the opportunity to reread the text, and thus should enhance the interpretability of the reading time data. Second, we dropped the disappearing picture condition for two reasons. It did not add much useful information in Experiment 1, and because subjects knew that pictures would disappear frequently, the subjects may have adopted unusual reading or picture inspection strategies.

Method

Subjects. Thirty-six undergraduate students at the University of Wisconsin-Madison contributed data. As before, they received both course credit for participating and a cash bonus based on the accuracy of their responses to question. Three subjects were replaced, one for failing to achieve above chance performance on the questions, and two because of computer failures.

Materials and design. Texts and diagrams were the same as those used in Experiment 1, but one practice text and four distractor texts were omitted, leaving a total of 2 practice and 28 experimental texts, 24 of which were scored, for each subject. The one change from Experiment 1 in the presentation of texts and diagrams was that a moving window, as described by Just, Carpenter, and Wooley (1982), was employed. The initial display consisted of dashes representing all non-space characters in the text. Upon a key press by the reader, one sector of the text appeared to replace the dashes corresponding to it. On the next key press, the previous sector was replaced again by dashes, and one new sector was revealed. Thus, the reading times measured represent the time during which the words in a segment of text were available for reading.

Picture availability and distance were again manipulated within subjects. Two levels of the picture variable were used: No Picture, and Full Picture. Therefore, each subject contributed 12 Near and 12 Far observations in each of the two picture conditions.

Results

Reading Times. Because reading time for an individual word is meaningful in the moving window presentation, analyses were performed on reading times for the anaphor phrases themselves as well as for the full

sentences containing them. There were no significant effects on the phrase reading times, $\underline{F}s < 2.4$, $\underline{p} > .10$ for all analyses performed. Reading times for the full sentences are shown in Figure 5. The pattern of results is very similar to that found in Experiment 1. There were significant effects of picture ($\underline{F1}(1,35) = 19.49$, $\underline{MSE} = 595377$, $\underline{F2}(1,23) = 12.83$, $\underline{MSE} = 503150$), and picture by distance interaction ($\underline{F1}(1,35) = 5.28$, $\underline{MSE} = 590623$, $\underline{F2}(1,23) = 6.13$, $\underline{MSE} = 257488$). The effect of distance approached significance for subjects, $\underline{F1}(1,35) = 3.54$, $\underline{MSE} = 484865$, $.10 > \underline{p} > .05$, but not for t͏ͫts, $\underline{F2}(1,23) = 1.30$, $\underline{MSE} = 389154$. The same pattern of simple effects was found as in Experiment 1, with distance having a significant effect in the full picture condition ($\underline{F1}(1,35) = 5.51$, $\underline{MSE} = 858047$, $\underline{F2}(1,23) = 4.41$, $\underline{MSE} = 439072$), but a non-significant effect in the no picture condition ($\underline{F1}(1,35) = .48$, $\underline{MSE} = 217441$, $\underline{F2}(1,23) = .71$, $\underline{MSE} = 207570$). Note that this pattern is contrary to the predictions derived from memory and the perceptual hypotheses.

<u>Accuracy.</u> Percent correct responses to comprehension questions are shown in Figure 6. As in Experiment 1, main effects of picture ($\underline{F1}(1,35) = 89.7$, $\underline{MSE} = 136.10$, $\underline{F2}(1,23) = 26.03$, $\underline{MSE} = 312.53$) and distance ($\underline{F1}(1,35) = 25.66$, $\underline{MSE} = 74.73$, $\underline{F2}(1,23) = 12.71$, $\underline{MSE} = 100.46$) were both significant. The picture-by-distance interaction was not significant, both $\underline{F}s < 1$. Failure to find this interaction is contrary to both the memory and the perceptual hypotheses.

<u>Analysis By Reading Speed.</u> In Experiment 2, slow readers performed significantly better on the comprehension measure than did fast readers (80.7% vs. 65.5%, $\underline{F1}(1,34) = 11.57$). For the sentence reading times, the three-way interaction of reading speed, distance, and picture was again significant ($\underline{F1}(1,34) = 5.89$); for this experiment, the reading speed by distance interaction was also significant ($\underline{F1}(1,34) = 12.65$), and again simple effects analyses indicated the presence of a distance by picture interaction for slow readers ($\underline{F1}(1,34) = 14.21$), but not for fast readers ($\underline{F1}(2,88) = .11$). As Figure 7 indicates, the basis of the interaction is that reading time increased with greater distance, but only for the slow reader group, and only when a picture was available. Analyzing the phrase time measure indicated that no interactions involving reading speed and other variables were significant, $\underline{F1}$'s < 2.70, $\underline{p} < .10$.

<u>Analysis By Half of Experiment.</u> The same pattern of results was obtained as in Experiment 1. Second half comprehension exceeded first half by 3.7%, but main effects and interactions of half on this dependent measure were not significant ($\underline{F1} < 2.71$, $\underline{p} > .10$ for all). Reading times for critical sentences were 877 msec longer in the first half, and this difference was significant ($\underline{F1}(1,35) = 24.88$, $\underline{MSE} = 2230202$). Interactions between half and other factors were non-significant, with $\underline{F1}s < 1$.
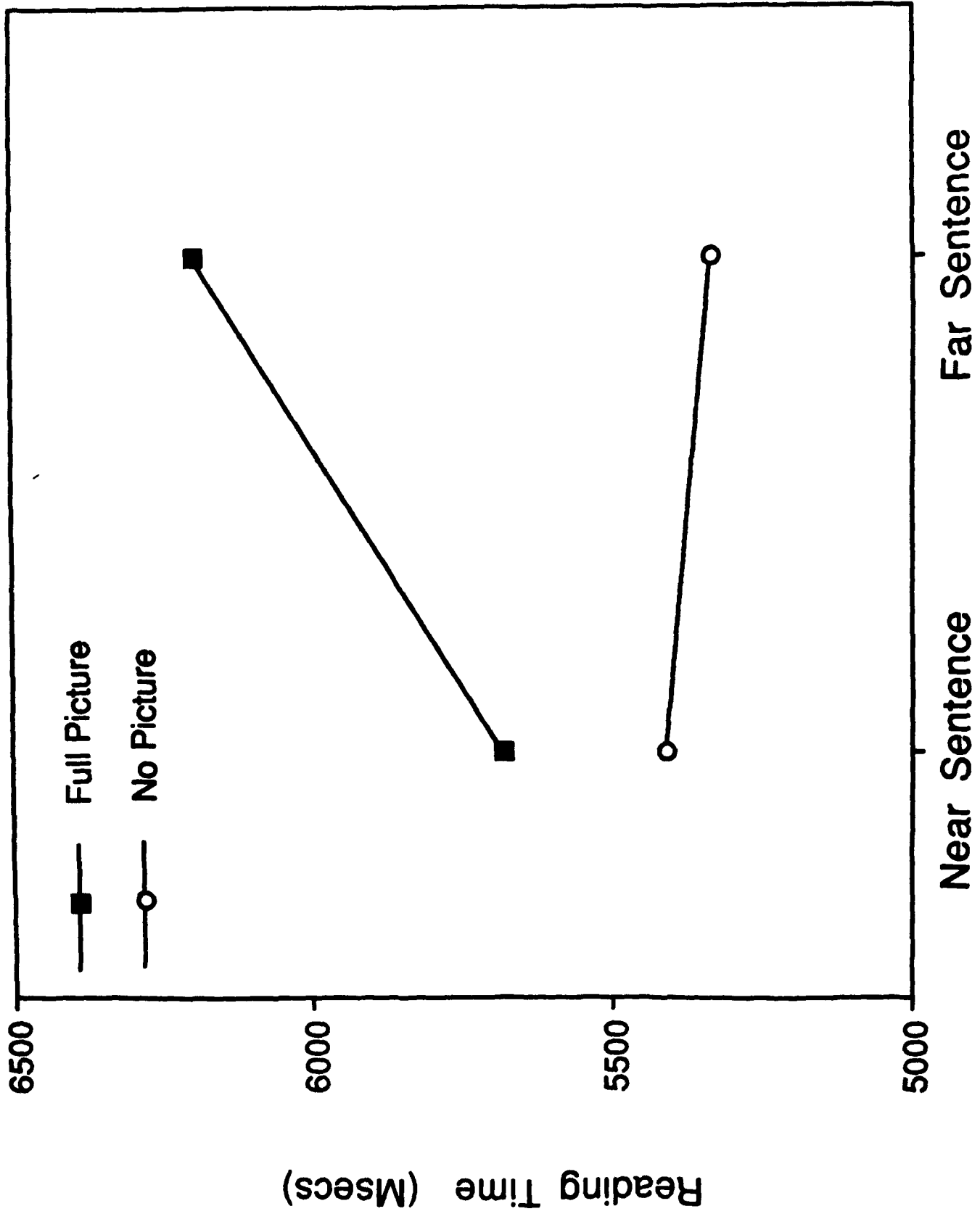
Figure 5. Mean of subjects' median reading times in Experiment 2 as a function of anaphor distance and picture presence.
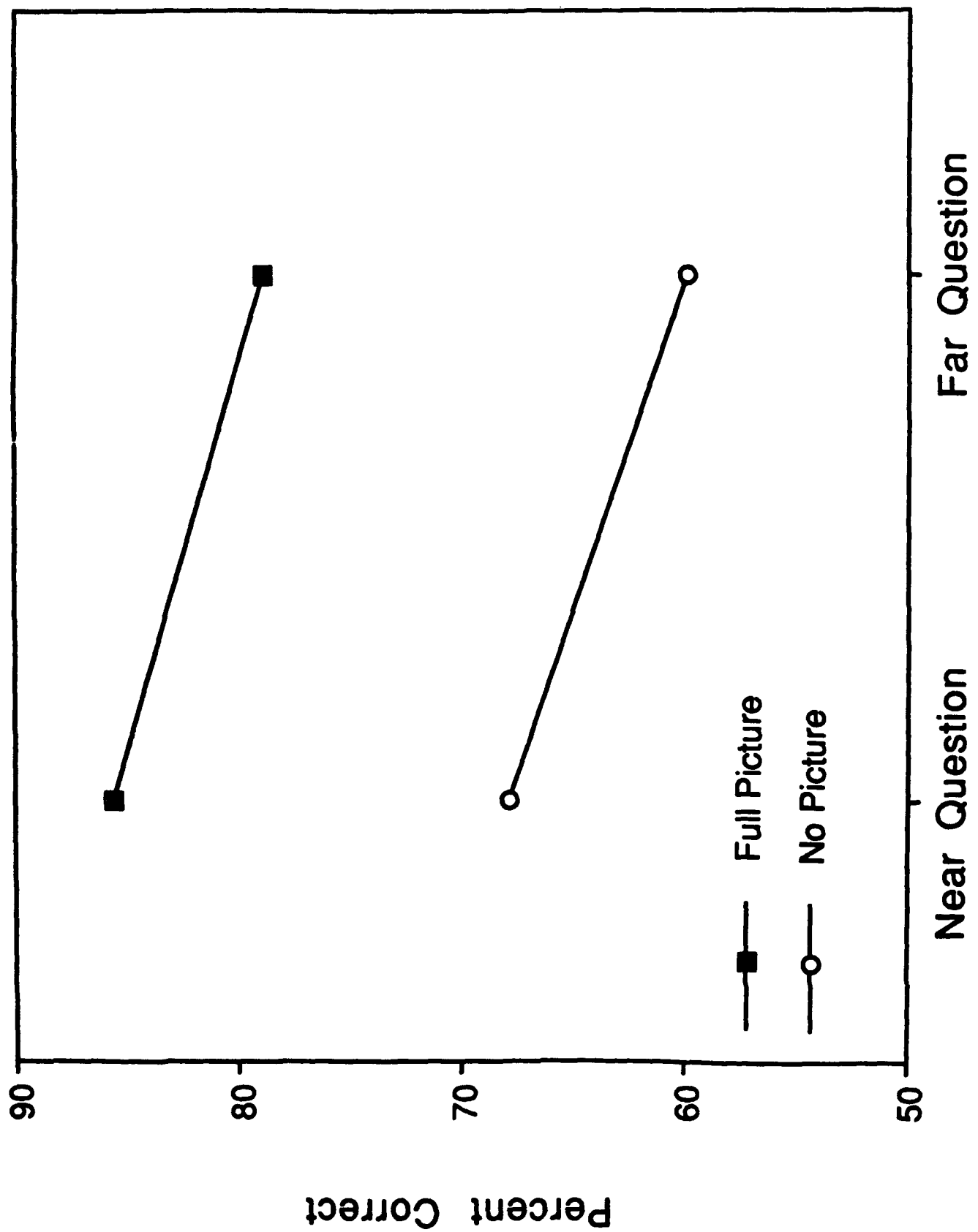
Figure 6. Mean percent correct in Experiment 2 as a function of distance and picture conditions.
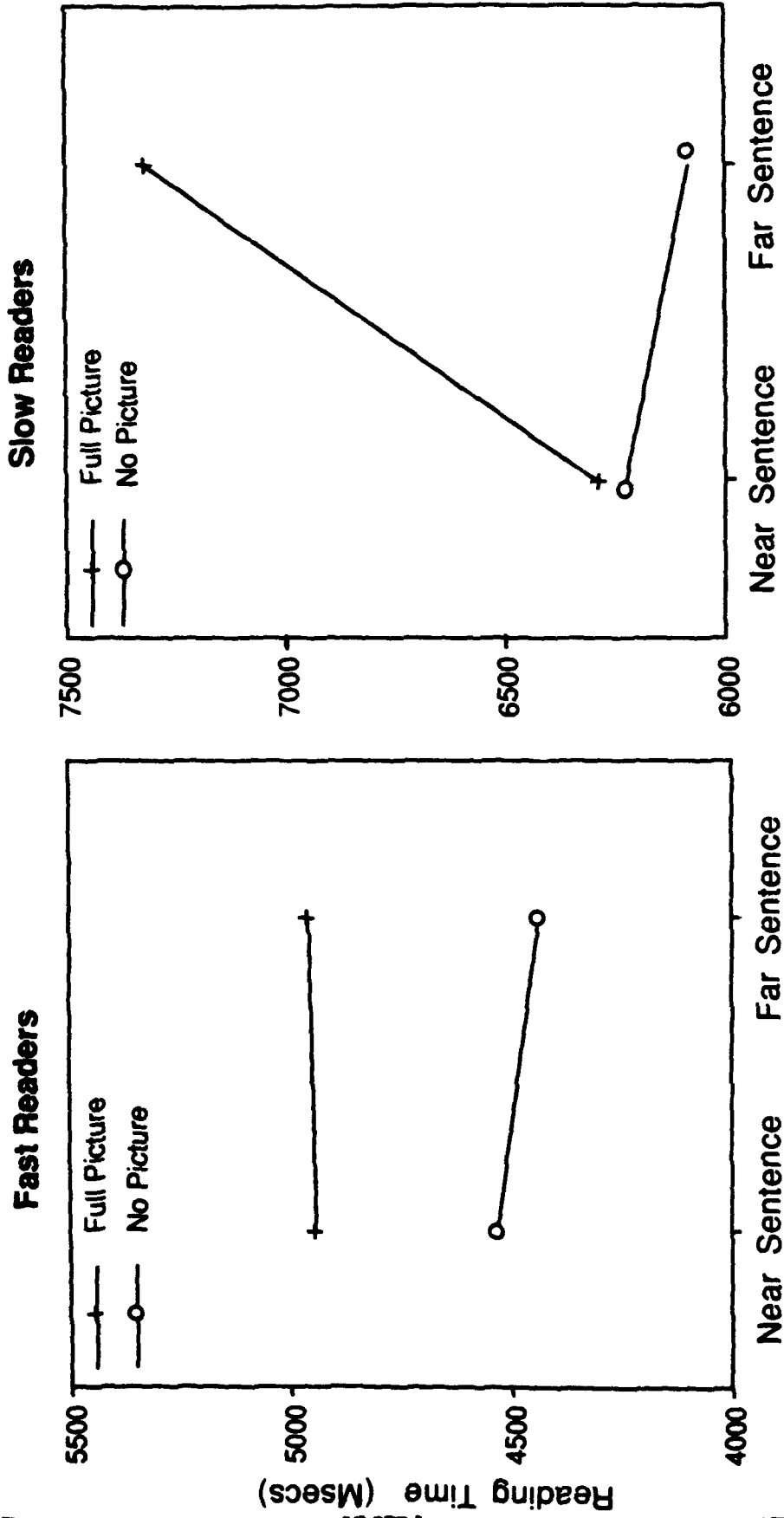
Figure 7. Reading times in Experiment 2 after performing a median split on overall reading speed. Panel (a) shows the pattern of reading times for slow readers, and panel (b) for fast readers.

Discussion

Although the methodology used in Experiment 2 differs from that in Experiment 1 in several important respects, the results of the two experiments are quite similar. In particular, for the reading times, there was a significant interaction between distance and picture condition, but the interaction was just the opposite of that expected by the memory and perceptual hypotheses. Combined with the failure to find an interaction in the comprehension data, there are strong grounds for rejecting the hypotheses.

It is not surprising that the reading time measure revealed an effect of distance only for the full anaphor sentences, rather than on the reading time for the anaphor itself. Ehrlich and Rayner (1983) demonstrated just such an effect using durations of eye fixations as the dependent variable. They concluded that only lexical access and syntactic parsing are carried out immediately upon fixation of a word; other processes, such as assigning a referent, are completed later. Van den Broek and Thurlow (1990) reported an analogous finding when measuring the time to make causal inferences. That is, the increase in reading time (with difficulty of the inference) occurred after the critical sentence demanding the inference, not while reading that sentence.

General Discussion

In this discussion we will consider two issues, possible problems with our conclusion that pictures do not facilitate anaphor resolution, and what accounts for the large facilitation in comprehension due to pictures.

There are several ways in which our results are limited, but not critically so. First, we used only two values of distance, near and far. Perhaps the values we choose are not optimum for demonstrating effects consistent with the memory and perceptual hypotheses. This possibility can be dismissed readily. We did obtain distance effects in both reading time and in a measure of comprehension. The problem was in failing to find the predicted interactions. Also, Ehrlich and Rayner manipulated distance over three values, near, intermediate (roughly corresponding to our near), and far. The largest difference that they observed were between the intermediate (our near) and the far conditions.

A second limitation is that we used only one type of anaphora, referring to a part by its spatial location. This is somewhat unusual in the literature, but it is just the sort of anaphor that should have revealed a benefit from a spatially organized picture. Nonetheless, no benefit (in anaphor resolution) was found. We used a different sort of anaphor, exact repetition of a part's name, in several pilot experiments (some in which whole

sentences were exposed with each key press and some using the moving window technique). None of those experiments revealed any evidence in support of the memory or perceptual hypotheses.

Third, one could argue that repetition of a part's spatial location can be an inelegant form of reference. That is, when a concept is foregrounded (the current topic), it is easier to refer to the concept using a pronoun than a noun phrase; full noun phrases seem to be required only when the concept is not the current topic (see Garrod and Sanford, 1990, and Gordon, Grosz, Gertner, and Rabin, 1990, as examples). Whereas this criticism is well-founded, it predicts just the opposite of what we found. That is, if the noun phrase is an inelegant form of reference in the near condition (because the antecedent is the subject of the previous sentence so may well be foregrounded), then reading times should be slower in the near condition than in the far condition. A glance at either Figures 2 or 5 will confirm that this did not occur.

Finally, our conclusion rests on accepting the null hypothesis of no interaction between picture condition and distance, and so the question arises as to whether or not the experiments had sufficient power to detect the interaction. In Experiment 1, there was sufficient power to have a 0.5 chance of detecting an interaction effect (gamma) as small as .284. In Experiment 2, an effect size of .325 could have been detected with a probability of 0.5. Considering the two experiments as independent replications, there was a greater than 0.75 probability of detecting an interaction effect as small as .325. Thus, it seems safe to conclude that the interaction is either absent or small.

There is no doubt that pictures facilitated comprehension. The picture effect was significant in both experiments (by subjects and by texts), and in Experiment 2 it was quite large; subjects averaged 64% correct in the no picture condition and 82% correct in the picture condition. If pictures are not helping to resolve anaphors, what is behind this facilitation? Clearly, there is little in the present data that will help to specify a single answer, but the data are consistent with several possibilities, and inconsistent with at least one other. The one unlikely answer is that having a picture acts to increase study time: that is, the picture slows down reading and thereby produces better comprehension. Although the data are roughly consistent with this hypothesis (longer reading times and better comprehension with pictures than without), a finer-grained analysis reveals trouble. For example, in Experiment 2 in the near condition, there is little difference in reading time for full pictures and for no pictures, however there is a large difference in the comprehension scores. Also, in both experiments, subjects took longer to read the far sentence, but did more poorly on the far comprehension question.

One hypothesis that is consistent with the data is dual code theory (Paivio, 1986). In outline, processing the

picture results in a long-term spatial representation, whereas processing the text produces a long-term verbal representation. The two representations are different in kind, but there may be associations relating concepts with the same referent. On this account, there is no reason to suspect that pictures would help in the on-line resolution of anaphora because that is a verbal/linguistic task carried out separately from pictorial processing. Nonetheless, the pictorial representation may be useful when answering the comprehension questions. When the encoded verbal information is insufficient to provide an answer, the subject could consult the pictorial representation for the correct answer. There is no reason to suspect that the quality of the pictorial representation would vary with the linguistic variable of distance, hence, the independence of distance and picture conditions is consistent with this approach. Note that this hypothesis does not exploit the concept of working memory management.

A second possibility is that the pictures and the text interact in creating a more effective representation than that based on either modality alone. For example, the picture may help to disambiguate the text and thereby contribute to the encoding of extra-textual relationships. For example, although the text in Table 1 gives the relative spatial positions of the operculum, the columella, and the pseudopodium, the text does not specify that the three structures are contiguous. Knowing that the structures are contiguous should facilitate the encoding of spatial and other relationships. That is, knowing that the operculum maintains internal pressure directly on the columella, presumably makes it easier to understand the relationship between the internal pressure and the popping and release of the spores. This second possibility was supported by Glenberg and Langston (in press). Their data indicated that a picture could help to emphasize particular relationships.

This second possibility that pictures and text interact is consistent with the concept of working memory management in two ways. First, because the picture specifies the exact spatial relations of the parts, these relationships can be represented (at least initially) by the spatial component of working memory. Second, it is probably easier to maintain spatial relationships in working memory given the direct perceptual support of the picture than if the spatial relationships had to be maintained in the absence of perceptual support. These suggestions remain to be empirically tested.

References

Carpenter, P., & Just, M. (1977). Integrative processes in comprehension. In D. Laberge & S. Samuels Eds.), Basic processes in reading: perception and comprehension (Pp. 217-242), Hillsdale, NJ: Lawrence Erlbaum.

Clark, H. H., & Sengul, C. J. (1979). In search of referents for nouns and pronouns. Memory and Cognition, 7, 35-41.

Daneman, M.,& Carpenter, P. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior, 19, 450-456.

Ehrlich, K., & Rayner, K. (1983). Pronoun assignment and semantic integration during reading: Eye movements and immediacy of processing. Journal of Verbal Learning and Verbal Behavior, 22, 75-87.

Fletcher, C. R., & Bloom, C. P. (1988). Causal reasoning in the comprehension of simple narrative texts. Journal of Memory and Language, 27, 235-244.

Garrod, S., & Sanford, A. (1977). Interpreting anaphoric relations: the integration of semantic information while reading. Journal of Verbal Learning and Verbal Behavior, 16, 77-90.

Garrod, S., & Sanford, A. (1990). Referential processing in reading: Focusing on roles and individuals. In D. A. Balota, G. B. Flores D'Arcais, & K. Rayner (Eds.), Comprehension processes in reading (pp. 465-86). Hillsdale, NJ: Erlbaum.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating general comprehension skill. Journal of Experimental Psychology: Learning, Memory and Cognition, 16, 430-445.

Glenberg, A. M., & Langston, W. E. (in press). Comprehension of illustrated text: Pictures help to build mental models. Journal of Memory and Language.

Gordon, P. C., Grosz, B. J., Gertner, A., & Rabin, K. (1990). The role of pronominal reference in discourse segment coherence. Paper presented at the meeting of the Psychonomic Society, November, 1990,

New Orleans.

Halliday, M. A. K., & Hasan, R. (1976). Cohesion in English. London: Longman.

Jakimik, J. & Glenberg, A. M. (1990). Verbal learning meets psycholinguistics: modality effects in the comprehension of anaphora. Journal of Memory and Language, 29, 582-590.

Just, M., Carpenter, P., & Woolley, J. (1982). Paradigms and processes in reading comprehension. Journal of Experimental Psychology: General, 111, 228-238.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. Psychological Review, 95, 163-182.

Larkin, J. H. & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11, 65-99.

Paivio, A. (1986). Mental representation: A dual coding approach. New York: Oxford University Press.

van den Broek, P,. & Thurlow, R. (1990). Reinstatements and elaborative inferences during the reading of narratives. Paper presented at the meeting of the Psychonomic Society, November, 1990, New Orleans.

Willows, D. M. & Houghton, H. A. (1987). The psychology of illustrations: I. Basic research. New York: Springer-Verlag.